

W^{\pm} Boson Production at Mid-rapidity in 500 GeV p+p Collisions in the PHENIX Experiment

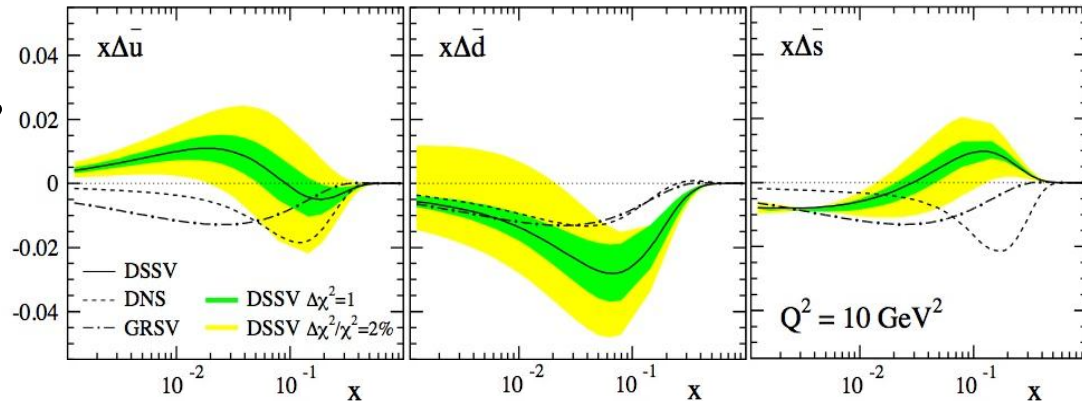
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Motivation for Spin Physics with Ws

- ✓ Key measurement: (anti-)quark flavor separated polarized PDFs

DSSV: PRL 101, 072001 (2008)

- ✓ Semi-inclusive polarized DIS measurements (SMC, HERMES, COMPASS) through fragmentation processes



- ✓ PHENIX exploits maximal-parity violation in W production in polarized pp collisions:

- no fragmentation involved: $p+p \rightarrow W^\pm \rightarrow e^\pm + \nu$ (mid-rapidity)
- high scale, Q^2 (set by W mass)
- extraction of $\Delta\bar{u}(x)$ and $\Delta\bar{d}(x)$
- also possible to probe $\bar{u}(x)/\bar{d}(x)$ ratio

W^\pm Boson Production in Polarized Proton Collisions

(Anti-)quark flavor separation:

Through $u\bar{d} \rightarrow W^+$ and $\bar{u}d \rightarrow W^-$

Maximal parity violation - W couples to only one helicity:

- ✓ For W^+
 - \underline{u} left-handed: Δu probed in polarized proton
 - \bar{d} right-handed: $\Delta \bar{d}$ probed in polarized proton
 - **parity violating longitudinal single spin asymmetry** is

$$A_L^{W^+} = - \frac{\Delta u(x_1)\bar{d}(x_2) - \Delta \bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}$$

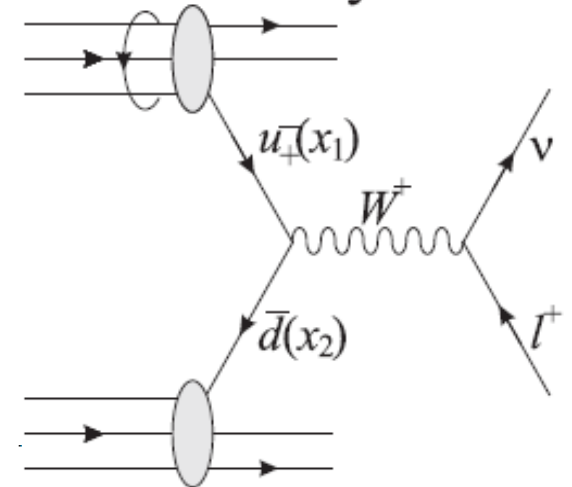
- ✓ For W^- , $\Delta \bar{u}$ and Δd probed

In experiment, denoting positive beam helicity by + and negative by -, polarized PDF's can be accessed by measuring:

$$A_L^W = \frac{1}{P} \times \frac{N^+(W) - N^-(W)}{N^+(W) + N^-(W)}$$

W^+ production example at LO:

Proton helicity = "+"

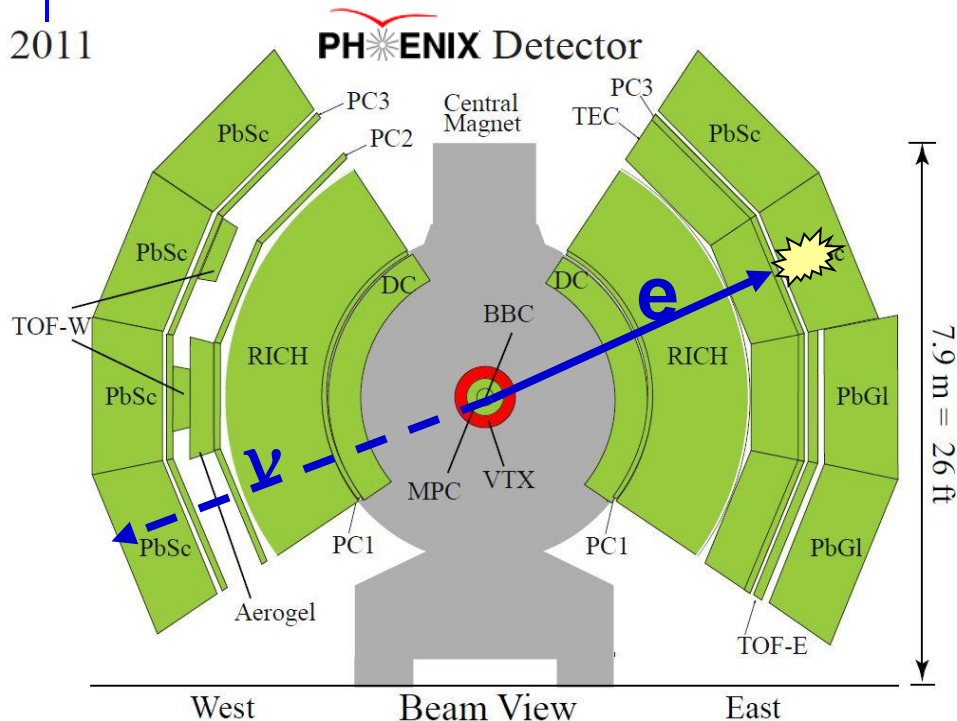


(Bunce et al., Ann. Rev. Nucl. Part. Sci. 50:525 (2000))

N is the electron yield, normalized by luminosity;
P is luminosity-weighted polarization

PHENIX Detector and Analysis Strategy

2011



Central arm spectrometers:

- $|\eta| < 0.35$ in rapidity
- 2 arms covering each $\Delta\phi = \pi/2$
- Electromagnetic Calorimeter ($\Delta\phi \times \Delta\eta \sim 0.01 \times 0.01$)
- Tracking: Charged tracks measured in Drift Chamber (DC) and Pad Chamber (PC1)

$$p+p \rightarrow W^\pm \rightarrow e^\pm + \nu$$

Detect high energy e^\pm in central arms of PHENIX

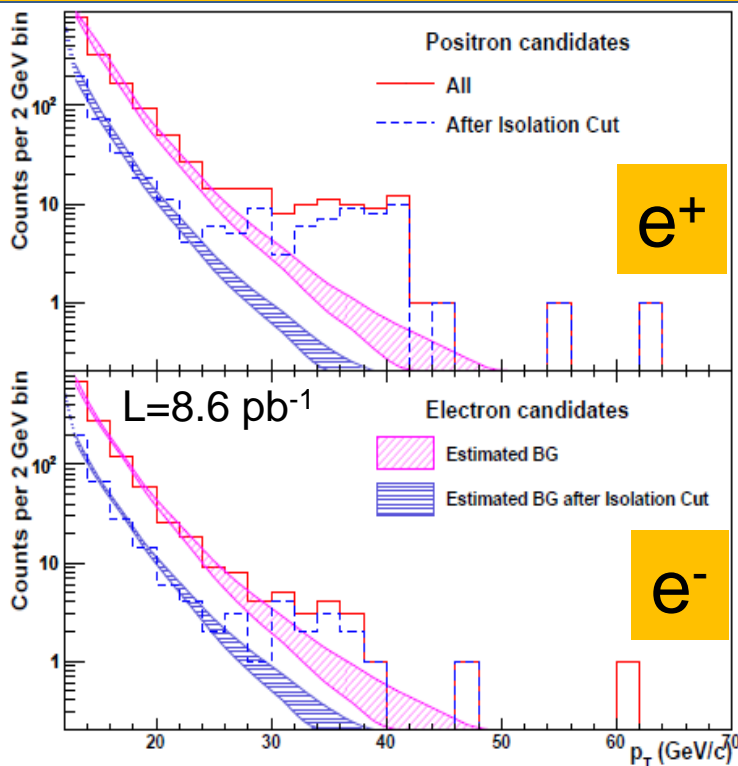
- EMC 4x4 Tower Sum Trigger
- High energy EM Calorimeter clusters matched to charged tracks
- Timing cut to reduce cosmic ray background
- E/p cut to reduce hadron bkg
- Isolation cut: Signature of a W event is that it is isolated, then sum up energy in a cone around electron/positron candidate of 0.5 rads $\Sigma E < 2\text{GeV}$ (isolation cut used in 2009 data analysis; tune it for 2011 analysis)

Run 2009 Measured Spectra: Signal and Background

- ✓ Identify $W^\pm \rightarrow e^\pm$: rely on excess of events over background

Data:

EMCal cluster distribution after subtracting cosmic background \times (Conversion + Accidental) \times Tracking Acceptance



MC driven BG estimation:

+

(NLO Hadrons thru Geant + FONLL c/b)
 \times Normalization from fit to 10-20 GeV

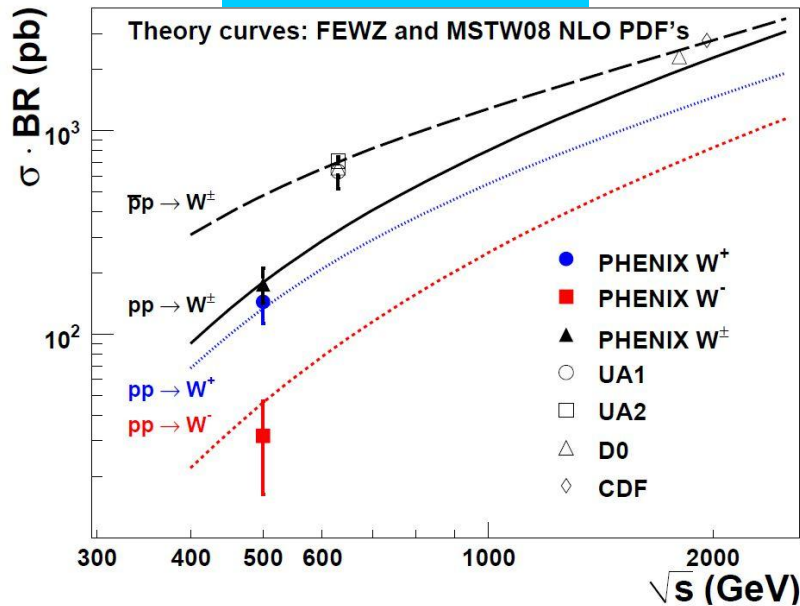
- Expected signal: **Jacobian peaks** for W^+ and W^-
- $W^- \rightarrow e^-$ signal has fewer counts than $W^+ \rightarrow e^+$ signal as expected
- Background bands include uncertainty in the photon conversion probability: photon conversions $\gamma \rightarrow e^+e^-$ (before the Drift Chamber) - simulation study is in progress for 2011 data analysis

Phys. Rev. Lett. 106, 062001(2011)

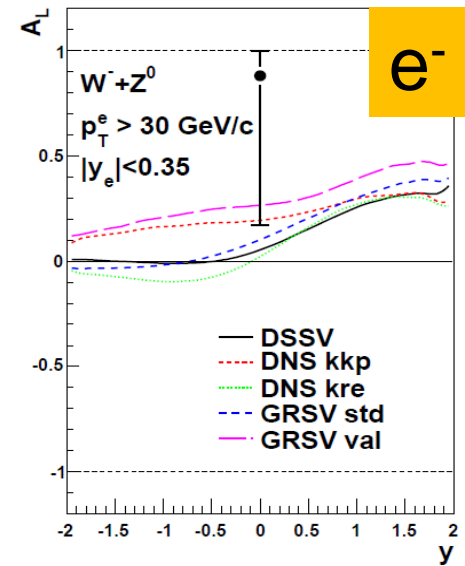
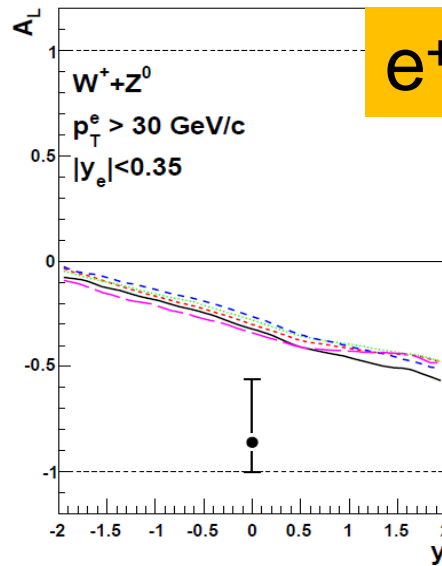
PHENIX Run 2009 results

- ✓ First W measurements in 500 GeV longitudinally polarized pp collisions
- ✓ Integrated luminosity is $\int \mathcal{L} dt = 8.6 \text{ pb}^{-1}$
- ✓ Polarization is $\langle P \rangle = 0.39 \pm 0.04$

Cross section



A_L



Phys. Rev. Lett. 106, 062001(2011)

$$\sigma(pp \rightarrow W^+ X) \times \text{BR}(W^+ \rightarrow e^+ \nu_e) = 144.1 \pm 21.2(\text{stat})_{-10.3}^{+3.4}(\text{syst}) \pm 21.6(\text{norm}) \text{ pb}$$

$$\sigma(pp \rightarrow W^- X) \times \text{BR}(W^- \rightarrow e^- \bar{\nu}_e) = 31.7 \pm 12.1(\text{stat})_{-8.2}^{+10.1}(\text{syst}) \pm 4.8(\text{norm}) \text{ pb}$$

$$A_L^{e^+} = -0.86_{-0.14}^{+0.30}$$

$$A_L^{e^-} = 0.88_{-0.71}^{+0.12}$$

PHENIX Mid-rapidity W^\pm in Run 2011

- ✓ Run 2011 500 GeV
longitudinally polarized p+p:

**Larger sample with
improved polarization**



Year	\sqrt{s} [GeV]	$\int Ldt$ [pb $^{-1}$]	Pol. [%]
2009	500	8.6	39
2011	500	~17	~46

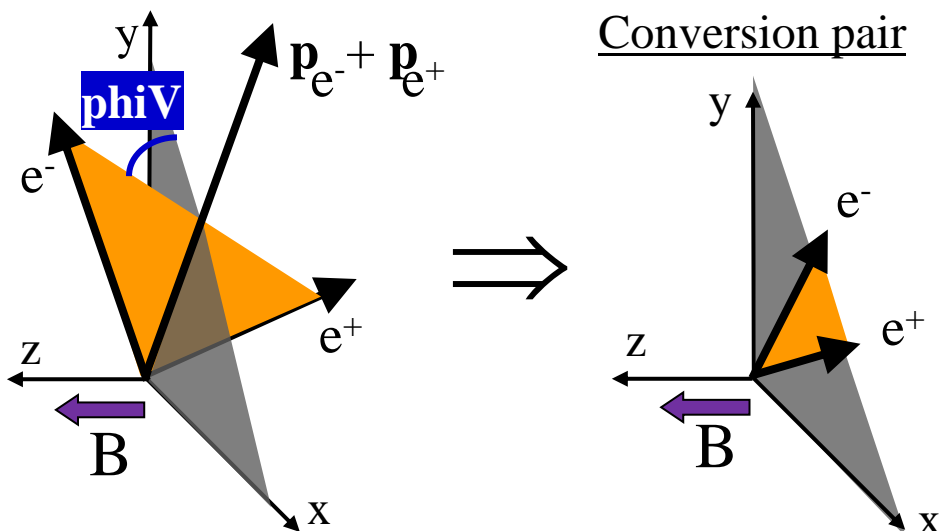
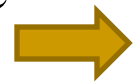
- ✓ Data is being analyzed
- ✓ Changes to central arm from 2009 to 2011: HBD removed, Si VTX installed (!);
Si VTX Radiation length = 13.5%
=> Increased rate of conversions by ~3 – require complementary analysis
- ✓ Si VTX was under commissioning in Run 2011 500 GeV p+p
- ✓ To subtract photon conversion background, proceed with the simulation study on a set of kinematic variables (in progress - next slide)
- ✓ Acceptance calculation in progress. Acceptance factors: • Solid angle, • Vertex cut, • Trigger efficiency, • Calorimeter hot/dead towers, • Tracking efficiency

Run 2011 Data Analysis in Progress

Simulation study to remove **photon conversion** ($\gamma \rightarrow e^+e^-$) background

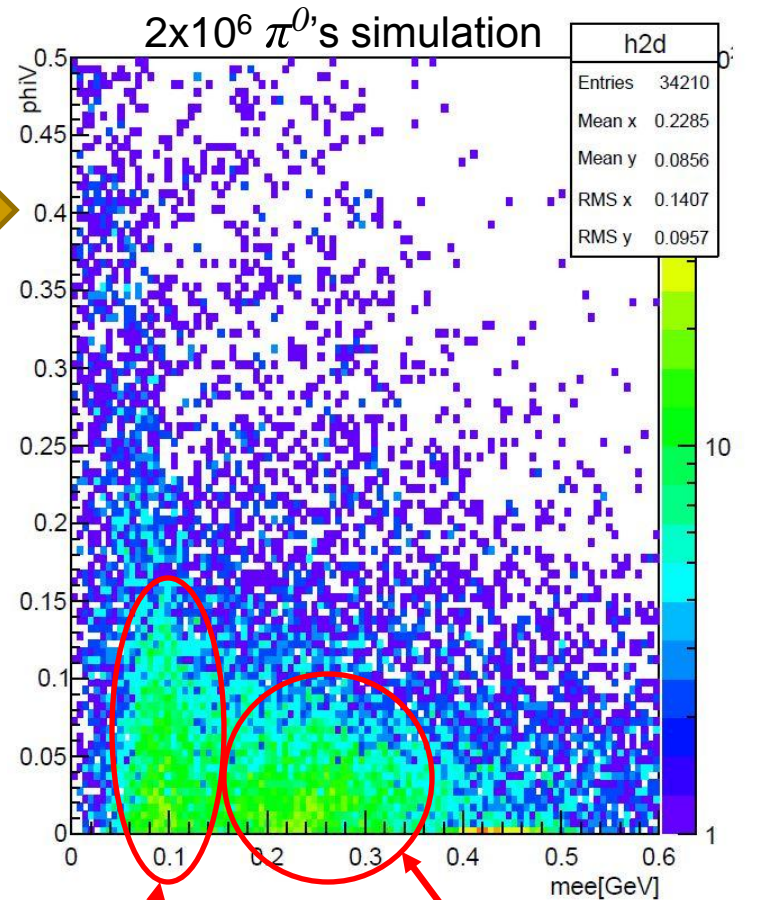
✓ Every high energy e^\pm candidate is paired with charged tracks of opposite sign:

• orientation angle of the pair in the magnetic field (**phiV**) vs. apparent invariant mass m_{ee}



- ✓ In the simulation data, know exactly origin of every track
- ✓ Similar pattern seen in real data

✓ **Analysis is in progress...**



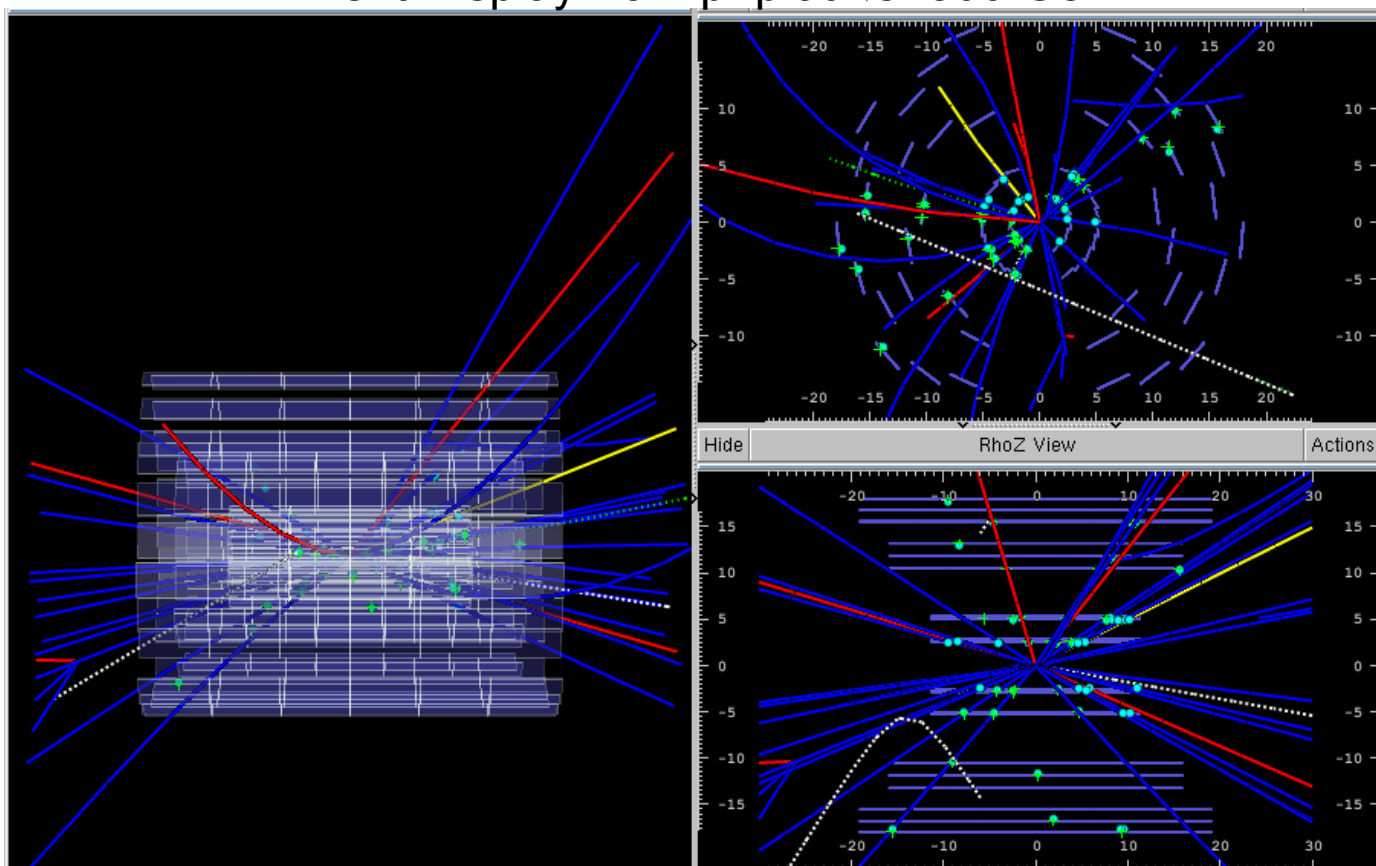
Conversions in SiVTX barrels

Conversions in SiVTX electronics support

PHENIX in Run 2012

- ✓ Run 2012 500 GeV p+p collisions started on March 18, 2012
- ✓ SiVTX detector is fully operational in Run 2012: will be used in central arm W analysis

Event Display from p+p at $\sqrt{s}=500$ GeV



Summary

- ✓ Run 2009:
 - First W^\pm cross section and A_L results in 500 GeV p+p collisions. Within errors, it is consistent with the predictions
- ✓ Run 2011:
 - Recorded larger data sample with improved polarization in comparison to Run 2009
 - Data analysis is in progress, including analysis technique developed to subtract background from conversion in additional material after important detector upgrades
- ✓ Run 2012:
 - Data taking ongoing
 - SiVTX is fully operational, will be used in the analysis
 - Get more data

Backup slides:

W^\pm Boson Production in Polarized Proton Collisions

(Anti-)quark flavor separation:

Through $u\bar{d} \rightarrow W^+$ and $\bar{u}d \rightarrow W^-$

(a) u is left-handed:

Δu probed in polarized proton

(b) \bar{d} is right-handed:

$\Delta \bar{d}$ probed in polarized proton

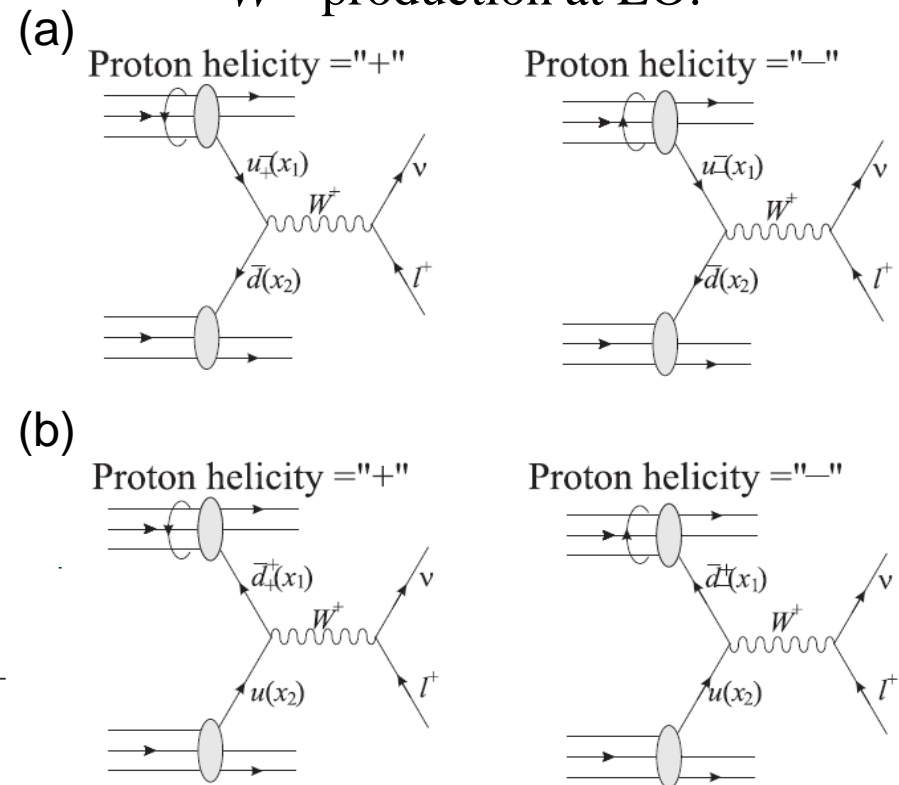
In general, asymmetry is

a superposition of (a) and (b):

$$A_L^{W^+} = -\frac{\Delta u(x_1)\bar{d}(x_2) - \Delta \bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}$$

✓ For W^- , $\Delta \bar{u}$ and Δd probed

W^+ production at LO:



(Bunce et al., Ann. Rev. Nucl. Part. Sci. 50:525 (2000))

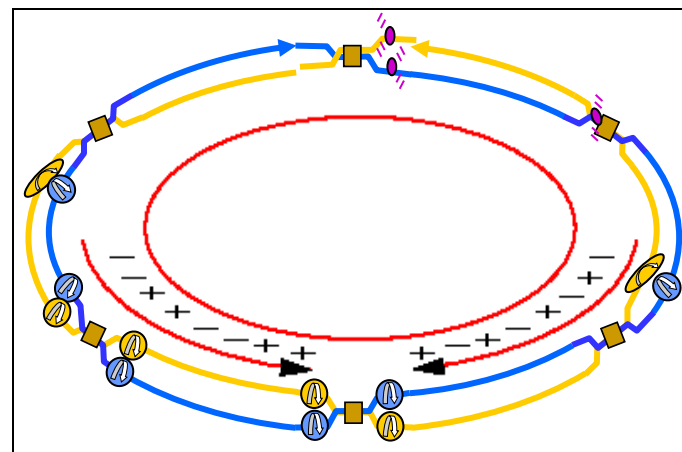
Parity Violating Single Spin Asymmetry

Denoting positive beam helicity by + and negative by −, parity violating longitudinal spin asymmetry can be used to access polarized PDF's by measuring:

$$A_L^W = \frac{1}{P} \times \frac{N^+(W) - N^-(W)}{N^+(W) + N^-(W)}$$

N is the electron yield,
normalized by luminosity;
P is luminosity-weighted
polarization

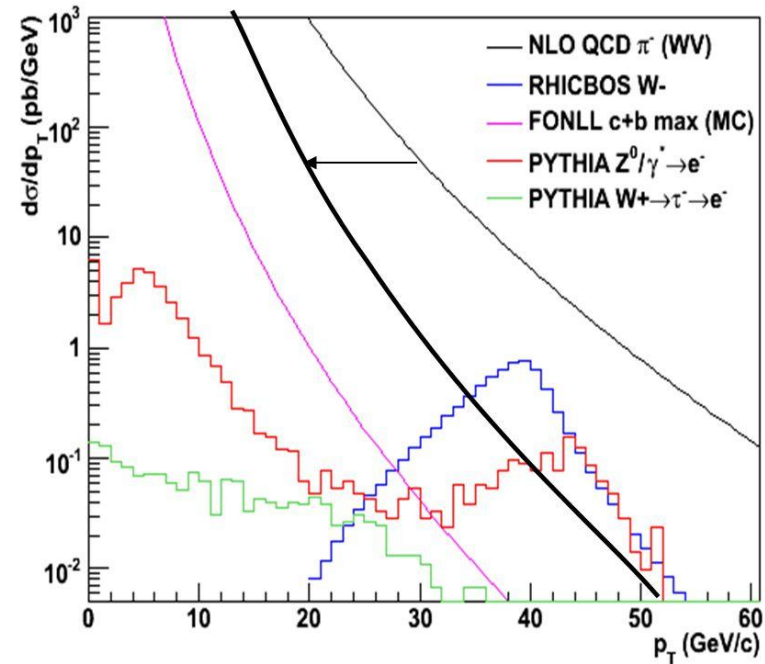
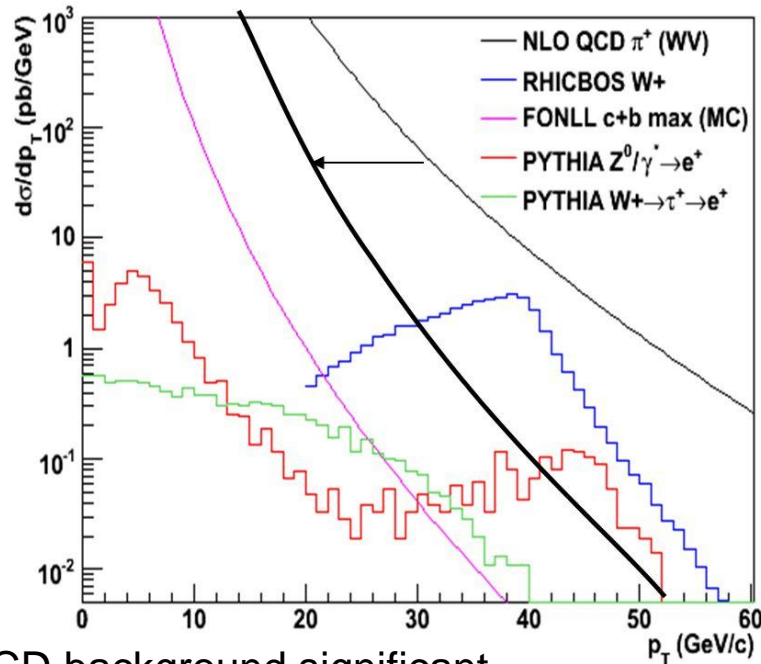
- ✓ At RHIC, up to 120 bunches in each ring, crossing every 106 ns, helicity of pairs ++, +−, −+, −− alternates rapidly
- ✓ Get one measurement treating “blue” beam as polarized, averaging over “yellow” beam
- ✓ Get second measurement treating yellow beam as polarized, averaging over blue beam



Signal and Background components

Identify $W^{\pm} \rightarrow e^{\pm}$: rely on excess of events over background

✓ Signal: **Jacobian peaks** for W^+ and W^-



- ✓ QCD background significant
- ✓ c/b relatively small above 30 GeV
- ✓ $W \rightarrow \tau \rightarrow e$ is also small
- ✓ $Z \rightarrow e$ is part of the signal
- ✓ Not shown here but very important:
 - Hadronic shower in EMCal – hadronic response simulation and data study is in progress
 - Photon conversions $\gamma \rightarrow e^+ e^-$ (before the Drift Chamber) - simulation study is in progress